TITLE: HANDWHEEL-OPERATED DEVICE

Field of the Invention

This invention relates to a handwheel-operated device and to a method of controlling a motor of a handwheel-operated device by sensing rotation of the handwheel and causing the motor to rotate a chuck in dependence upon the rotation of the handwheel.

Background to the Invention

Mechanical devices of the kind having a handwheel connected to a chuck through a gear train, so that rotation of the handwheel causes a corresponding rotation of the chuck are well known. Hand drills and hand whisks are examples of such devices. These handwheel-operated devices are popular because a handwheel affords a high degree of control over the speed of rotation of the chuck. However, the magnitude of the speed and/or torque that can be developed at the chuck is limited by the magnitude of the speed and/or torque applied to the handwheel, which must be provided by the user. Such devices are therefore unsuitable for use over long periods or by users who lack physical strength, or if high levels of both speed and torque are required.

Summary of the Invention

According to a first aspect of the invention there is provided a handwheel-operated device comprising a body, a handwheel and a chuck, the handwheel and the chuck being rotatable relative to the body, and the device further comprising a first motor operable to rotate the chuck, first sensor means responsive to rotation of the handwheel and first control means operable in conjunction with the first sensor means to cause the first motor to rotate the chuck in dependence upon an angular displacement and/or angular velocity of the handwheel.

The invention therefore provides a handwheel-operated device that is operable by a user in the same manner as a conventional handwheel-operated device, such as a hand drill or a

hand whisk, but which, for a particular speed and/or torque applied to the handwheel, is capable of developing considerably more speed and/or torque at the chuck than would a conventional handwheel-operated device.

The first control means may advantageously be operable to modulate a voltage applied to the first motor.

The first control means may advantageously be operable to modulate the voltage applied to the first motor such that the magnitude of the voltage is substantially proportional to the angular velocity of the handwheel.

This type of first control means is relatively straightforward to implement.

The first control means is preferably operable to modulate the voltage applied to the first motor such that an angular displacement and/or angular velocity of the handwheel results in a corresponding angular displacement and/or angular velocity of the chuck.

With this type of first control means, the response of the chuck to rotation of the handwheel is much closer to that of a conventional handwheel-operated device, where the handwheel and chuck are mechanically coupled to one another, for example by a gear train, because changes in the loading on (i.e. resistance to rotation of) the chuck do not alter the relationship between handwheel and chuck position and/or speed.

The first control means is more preferably operable to modulate the voltage applied to the first motor in dependence upon the angular velocity of the handwheel such that the angular velocity of the chuck is non-linearly related to the angular velocity of the handwheel, the ratio of handwheel speed to chuck speed decreasing with increasing handwheel speed. An increase in handwheel speed causes a greater than proportionate increase in chuck speed, and this type of first control means therefore enables a user to obtain very precise control of the angular displacement of the chuck at low speeds of rotation of the handwheel, yet also to obtain high angular velocities of the chuck that would otherwise require speeds of

rotation of the handwheel that would be difficult or impossible for the user to achieve or sustain.

Precise control of the angular displacement of the chuck is useful where the device is used, for example, as a screwdriver, and a user wishes to align a screwdriver bit in the chuck of the device with a slot in the head of a screw.

Preferably the first control means is operable to cause the polarity of the voltage applied to the first motor to be dependent on the sense of rotation of the handwheel so that changing the direction of rotation of the handwheel reverses the polarity of the voltage applied to the first motor, and hence reverses the direction of rotation of the chuck.

The first control means may advantageously include a proportional-plus-integral (PI) controller. In that case, the first control means may advantageously be operable to turn off the PI controller if the speeds of rotation of the handwheel and chuck fall below respective first threshold speeds.

Preferably the first control means is operable to turn on the PI controller if the speed of rotation of the handwheel rises above a second threshold speed. Preferably the second threshold speed is greater than the first threshold speed.

Turning off the PI controller at low speeds of rotation of the handwheel has been found to be necessary to prevent "creep" of the chuck, that is slow rotation of the chuck when the handwheel is stationary, due to steady-state errors in the PI controller.

The device may advantageously further comprise a variable low-pass signal filter operable to receive signals representative of the angular displacement and/or angular velocity of the handwheel from the first sensor means and to transmit signals below a cut-off frequency to the first control means and to attenuate signals above the cut-off frequency so as to prevent them from reaching the first control means, the cut-off frequency being determined by the angular velocity of the handwheel.

Preferably the variable low-pass signal filter is operable to decrease the cut-off frequency with increases of angular velocity of the handwheel up to a threshold angular velocity, above which increases of angular velocity of the handwheel do not affect the cut-off frequency.

The effect of the variable low-pass signal filter is to cause the first control means to react relatively quickly to changes of angular displacement and/or angular velocity of the handwheel at low speeds of rotation of the handwheel, and relatively slowly to changes of angular displacement and/or angular velocity at higher speeds of rotation of the handwheel. This has been found to be necessary to give an accurate response of the speed of rotation of the chuck to changes of the speed of rotation of the handwheel at low speeds of rotation of the handwheel, which gives a user of the device the same impression of control of the speed of rotation of the chuck as is obtained with a conventional mechanical device, but avoids an overly abrupt response of the speed of rotation of the chuck to changes of the speed of rotation of the handwheel at high speeds of rotation of the handwheel. Such an abrupt response of the speed of rotation of the chuck to changes of the speed of rotation of the handwheel is generally prevented in a conventional mechanical device as a result of the inertia of the handwheel, gear train and chuck of the mechanical device.

The first sensor means may advantageously comprise an angular displacement sensor. Suitable angular displacement sensors include a claw pole motor, an arrangement of a slotted disc rotatable relative to one or more optical sensors, or an arrangement of a multipole magnet rotatable relative to one or more Hall effect sensors and/or coils, which may be one or more printed coils on a printed circuit board. Where the arrangement of the multipole magnet and one or more coils is used, the first control means may be operable either to count pulses generated by the one or more coils, or to sample analogue voltage signals generated by the one or more coils. Typically the slotted disc or multipole magnet is mounted on a shaft of the angular displacement sensor. In that case, the handwheel may advantageously be attached to the shaft of the angular displacement sensor.

Preferably, however, a first gear wheel is attached to the shaft of the angular displacement sensor, a second gear wheel is attached to the handwheel, and the first and second gear wheels are engageable with one another either directly or via one or more intermediate gears, so that each revolution of the second gear wheel causes the first gear wheel to rotate through more than 360°, preferably a plurality of revolutions.

In this way, an inexpensive low-resolution angular displacement sensor, which produces, say, eight pulses during one revolution of its shaft, can be used, because each revolution of the handwheel will cause several revolutions of the shaft of the angular displacement sensor, and therefore a multiple of eight pulses during a revolution of the handwheel. Thus, provided that the ratio of the diameters of the first and second gear wheels is sufficiently large, the performance of an expensive high-resolution angular displacement sensor can be obtained using an inexpensive low-resolution angular displacement sensor.

Alternatively or additionally, the first sensor means may advantageously comprise a second motor, a shaft of which is coupled for rotation to the handwheel, and measurement means for measuring one or more parameters related to a speed and direction of rotation of the shaft of the second motor, and computation means operable to derive a speed and direction of rotation of the shaft of the second motor, and hence a speed and direction of rotation of the handwheel, from the one or more measured parameters.

Preferably the measurement means is operable to measure a back electromotive force (emf) generated by the second motor.

Where the first sensor means includes both a second motor and an angular displacement sensor, the shaft of the angular displacement sensor may advantageously be coupled for rotation to the rotor of the second motor, and the first gear wheel be attached to the shaft of the second motor.

The device may advantageously further comprise second sensor means operable to determine a torque developed by the first motor, torque feedback means coupled to the

handwheel and second control means operable in conjunction with the second sensor means to cause the torque feedback means to oppose the rotation of the handwheel.

In this way a user of the device may be provided with an indication of the torque developed by the first motor, which adds to the user's impression of a mechanical coupling between the handwheel and the chuck.

The second sensor means may advantageously comprise a force sensor and the first motor be mounted in the body of the device such that, in use, a torque developed by the first motor causes a torsional reaction force to be exerted on the force sensor.

The force sensor may advantageously be a piezoelectric crystal.

Alternatively, the second sensor means may advantageously comprise measurement means for measuring one or more parameters related to the torque of the first motor, and computation means operable to derive a torque of the first motor from the one or more measured parameters.

Preferably the measurement means is operable to measure a current supplied to the first motor.

The torque feedback means may advantageously comprise a variable brake engageable with the handwheel under the control of the second control means.

Where the first sensor means includes a second motor, the torque feedback means may more advantageously still comprise a second control means that is operable to supply current to the second motor so as to oppose the rotation of the handwheel.

The device may advantageously further comprise a battery to allow the device to be operated cordlessly.

In that case the device preferably further comprises third sensor means operable to determine an electromotive force (emf) developed by the battery, and the first control means is preferably operable in conjunction with the third sensor means to modulate the voltage applied to the first motor so that, at least until the battery is substantially discharged, decreases in the emf developed by the battery do not cause decreases of the speed of rotation of the chuck.

The device may advantageously further comprise fourth sensor means operable to determine a magnitude of a current supplied to the first motor, and the first control means may advantageously be operable in conjunction with the fourth sensor means to limit the magnitude of the current supplied to the first motor if the magnitude of the current exceeds a threshold level.

The device may advantageously further comprise biasing means and mechanical braking means, the biasing means being operable to urge the mechanical braking means into engagement with the handwheel so as to oppose the rotation of the handwheel.

The mechanical braking means has been found to smooth the response of the chuck to rotation of the handwheel, and to prevent unintended rotation of the handwheel, for example rotation of the handwheel due to the weight of a handle attached to the handwheel, which would otherwise cause unintended movement of the chuck.

Preferably the mechanical friction means is a felt-covered pad.

The handwheel may advantageously be provided with a handle movable between a folded position and an extended position.

The handwheel may advantageously further comprise latch means operable releasably to retain the handle in the extended position.

The body of the device and the handle of the handwheel may advantageously be formed such that in the folded position the handle engages with the body so as to prevent rotation of the handle relative to the body.

Preferably the device further comprises first switch means engageable with the handle, such that the first control means is operable to cause the first motor to rotate the chuck only when the handle is in the extended position.

Alternatively or additionally, the device may advantageously further comprise a first further manual control (for example a trigger switch), movable between an "off" position and an "on" position, wherein movement of the first further manual control to the "on" position when the handle is in its folded position causes the first motor to rotate the chuck.

Where the device includes both the first further manual control and the first switch means, the first control means may advantageously be operable to cause the first motor to rotate the chuck only when the handle is in the extended position and the first further manual control is moved to the "on" position. If the first further manual control includes biasing means operable to urge it into the "off" position, it may function as a "dead man's handle" such that if a user of the device drops the device in use, the first further manual control moves to the "off" position, in which position rotation of the handwheel does not cause rotation of the chuck.

Where the device includes the first further manual control, it may advantageously further comprise a second further manual control movable between "clockwise", "anti-clockwise" and "off" positions, wherein with the second further manual control in the "clockwise" or "anti-clockwise" positions, movement of the first further manual control to the "on" position when the handle is in its folded position causes the first motor to rotate the chuck clockwise or anti-clockwise, respectively.

Where the device includes the first and second further manual controls and the first switch means, the first control means may advantageously be operable to cause the first motor to

rotate the chuck only when the handle is in the extended position, the first further manual control is moved to the "on" position and the second further manual control means is moved to the "off" position.

The body of the device may advantageously comprise a first portion to which the handwheel is attached and a second portion attached to, and movable between a first and a second position relative to, the first portion.

In this way the device can be used by both left and right-handed users. In the first position of the second portion, the user can hold the second portion of the device in his left hand and operate the handwheel with his right hand. In the second position of the second portion, the user can hold the second portion of the device in his right hand and operate the handwheel with his left hand.

Preferably the device further comprises switch means operable by the first or second portion such that the switch means is closed when the second portion is in the first position and open when the second portion is in the second position and the first control means is operable when the switch means is closed to cause the chuck to rotate in one sense when the handwheel is rotated in a first sense, and operable when the switch means is open to cause the chuck to rotate in the opposite sense when the handwheel is rotated in the first sense.

Thus the response of the chuck to rotation of the handwheel is the same for both left and right-handed users of the device. That is, when the user rotates the handwheel away from him from top dead centre, the chuck rotates in a clockwise sense as seen from behind by the user, regardless of whether the second portion of the body is in the first or second position.

Preferably the device is a power tool.

In one embodiment of the invention the device is a cordless electric drill.

In another embodiment of the invention the device is an electric food blender.

According to a second aspect of the invention there is provided a method of controlling a motor of a handwheel-operated device, the device having a body, a handwheel, a chuck and a motor, the handwheel being rotatable relative to the body and the motor being operable to rotate the chuck relative to the body, the method comprising sensing rotation of the handwheel and causing the motor to rotate the chuck in dependence upon the angular displacement and/or angular velocity of the handwheel.

Brief Description of Drawing Figures

The invention will now be described by way of illustrative example and with reference to the accompanying drawings, in which:

Figure 1 is a perspective view of a first cordless drill in accordance with the first aspect of the invention;
Figure 2 is a schematic sectional view of the drill of Figure 1;
Figure 3 is a partial schematic sectional view of the drill of Figures 1 and 2 along the line A-A;
Figure 4 is a block diagram of a first control scheme for the drill of Figures 1 to 3;
Figure 5 is a block diagram of a second control scheme;
Figure 6 is a block diagram of a third control scheme;
Figure 7 is a block diagram of a fourth control scheme;
Figure 8 is a graph of amplifier gain and hence angular velocity of the chuck of the drill against angular velocity of the handwheel;
Figure 9 is a block diagram of a detail of the fourth control scheme;
Figure 10 is a block diagram of a fifth control scheme;
Figure 11 is a sectional view of the handwheel with the handle in a folded position;
Figure 12 is a sectional view of the handwheel with the handle in an extended position;
Figure 13 is a side view of an electric whisk in accordance with the first aspect of the invention;

Figure 14 is a block diagram of a motor model used in the fifth control scheme;

Figure 15 is a graph of cut-off frequency of a variable filter against angular velocity of the handwheel;

Figure 16 is a sectional view of a handwheel and a mechanical brake assembly;

Figure 17 is a perspective view of a second cordless drill in accordance with the first aspect of the invention;

Figure 18 is a sectional view of the drill of Figure 17;

Figure 19 is a perspective view of a third cordless drill in accordance with the first aspect of the invention;

Figure 20 is a partially cut away top view of a fourth cordless drill in accordance with the first aspect of the invention with one of two handwheels in an extended position;

Figure 21 is a sectional view of the drill of Figure 19;

Figure 22 is a partially cut away side view of a fifth cordless drill in accordance with the first aspect of the invention; and

Figure 23 is a top view of the drill of Figure 20 with both handwheels in the extended position.

Detailed Description of Embodiments

The cordless drill 10 of Figure 1 comprises a body 12, a handwheel 14 and a chuck 16. Except for the handwheel, the drill 10 superficially resembles a conventional drill, with a pistol grip 18, trigger switch 20 located in the pistol grip, and forward housing portion 22 located in front of the trigger. The handwheel 14 is attached to the portion 22. A rechargeable battery 24 is removably attached to the base of the body.

Turning to Figure 2, from which the battery 24 has been omitted for the purpose of clarity, the body 12 contains a first motor 26, a first rotary encoder 28, a gearbox 30, a second motor 32, a second rotary encoder (not shown), and first and second gear wheels 34 and 36, respectively. The body 12 further contains first control means in the form of a programmed microprocessor (not shown). The first rotary encoder 28 is made up of a multipole magnet and three Hall effect detectors and is attached to a first end of the spindle

of the first motor 26. The gearbox 30 is coupled to a second end of the spindle of the first motor 26 and to the chuck 16.

It will be appreciated by those skilled in the art that it may not be necessary to have a separate rotary encoder to implement the first rotary encoder 28, and that an arrangement, for example, of a magnetised gear wheel forming part of the gearbox 30 and three Hall effect detectors could be used instead to implement the first rotary encoder 28.

Moreover, it will be apparent to those skilled in the art that it is not essential that the first rotary encoder be attached to an end of the spindle of the first motor 26. Indeed, with very minor modifications to the drill, the rotary encoder could be placed at any point of the drive train comprising the first motor 26, gearbox 30 and chuck 16.

The first gear wheel 34 is attached to the spindle of the second motor 32. The second gear wheel 36 is attached to the handwheel 14 and to a spindle on which the handwheel rotates. The second motor 32 and the spindle on which the handwheel rotates are so located that the first and second gear wheels engage with one another, such that when the handwheel is rotated, the second motor is driven. The second gear wheel has a diameter that is between three and four times the diameter of the first wheel. For each revolution of the handwheel, therefore, the first gear wheel makes between three and four rotations, which increases the effective resolution of the second rotary encoder by between three and four times.

The handwheel 36 has a folding handle 38, which is shown in an extended position in Figures 1 and 2. The handle can be moved into a folded position, and is engageable with a microswitch (not shown) in the folded position, which microswitch disconnects the second rotary encoder from the microprocessor.

The first motor and gearbox are secured in the body by resilient mounts, which allow a small amount of torsional movement of the motor and gearbox relative to the body. The gearbox is formed with a radially outwardly projecting member 40. A piezoelectric crystal (not shown) is located to either side of the member 40 such that if torsional movement of

the motor and gearbox relative to the body occurs, a force is exerted on one or other piezoelectric crystal.

The arrangement of the member 40 and the piezoelectric crystals is shown more clearly in Figure 3, in which the piezoelectric crystals are denoted by reference numerals 42 and 44. Figure 3 is a sectional view along the line A-A of Figure 2.

Figure 4 shows a first control scheme for the drill in which the speed of rotation of the handwheel is measured and a pulse width modulated (PWM) voltage of magnitude proportional to the speed of rotation of the handwheel is applied to the first motor. As the handwheel is rotated, pulses are generated by the second rotary encoder (not shown). A first clock 46 determines the frequency of the pulses and generates a signal representative of the speed of rotation of the handwheel. The signal representative of the speed of rotation of the handwheel is used to generate a PWM voltage which drives a first field effect transistor (FET) h-bridge 48. The first motor 26 is connected across the first h-bridge 48.

Figure 5 shows a second control scheme in which the speed of rotation of the handwheel is measured and a feedback loop is used to ensure that the speed of rotation of the chuck is proportional to that of the handwheel. With only minor changes it would be possible instead to measure the angular displacement of the handwheel from a reference orientation and use the feedback loop to ensure that the angular displacement of the chuck from a reference orientation is proportional to that of the handwheel.

The first clock 46 determines the frequency of the pulses generated by the second rotary encoder to generate a signal representative of the speed of rotation of the handwheel. At the same time a second clock 52 determines the frequency of pulses generated by the first rotary encoder to generate a signal representative of the speed of rotation of the chuck. The signals representative of the speeds of rotation of the chuck and handwheel are compared by a microprocessor 50 to generate a speed error signal. The microprocessor

generates a PWM voltage to drive the first h-bridge 48 and control the speed of rotation of the first motor so as to reduce the magnitude of the speed error signal.

Figure 6 shows the control scheme of Figure 5 modified by a further feedback loop, which enables a retarding force to be applied to the handwheel, which retarding force is approximately proportional to the torque developed by the first motor 26. The control scheme shown in Figure 6 is as described in relation to Figure 5. However, a voltage developed by one of the piezoelectric crystals 42 and 44, which is subjected to a compressive force due to the reaction torque on the motor, is applied to a microprocessor 54. The microprocessor 54 generates a PWM voltage to drive a second FET h-bridge (not shown). The second motor 32 is connected across the second h-bridge and the PWM voltage generated by the microprocessor 54 causes the second motor to generate a torque which opposes the rotation of the handwheel.

Figure 7 shows a control scheme similar to that shown in Figure 6, but with a further feedback loop to ensure that the torque generated by the second motor to oppose the rotation of the handwheel is proportional to the torque generated by the first motor.

In the control scheme of Figure 7 the handwheel 14 is rotated and causes the spindle of the second motor 32 to rotate and the second rotary encoder 56 to generate pulses. The first clock 46 measures the frequency of the pulses from the second rotary encoder and generates a signal representative of the speed of rotation of the handwheel. An amplifier 58 applies a gain to the signal representative of the speed of rotation of the handwheel to generate an amplified speed signal. The gain of the amplifier increases with the magnitude of the signal representative of the speed of rotation of the handwheel. Figure 8 shows the gain characteristic 63 of the amplifier 58 with gain plotted against magnitude of the signal representative of the speed of rotation of the handwheel. Gain is plotted on the y-axis 65 and magnitude of the handwheel speed signal on the x-axis 67. The gain of the amplifier therefore determines the ratio of the speeds of rotation of the chuck and the handwheel. The amplified speed signal is applied to a first proportional plus integral (PI) controller 60.

The spindle of the first motor 26 rotates and causes the first rotary encoder 28 to generate pulses. A third clock 62 measures the frequency of the pulses and generates a signal representative of the speed of rotation of the first motor. The signal representative of the speed of rotation of the first motor is applied to the PI controller 60. A current sensor (not shown) measures the current flowing through the first motor and generates a signal representative of the current flowing through the first motor. The current sensor transmits the signal to the first PI controller 60. The first PI controller 60 generates a PWM voltage to drive the first h-bridge 48 to cause the spindle of the first motor to rotate at the speed determined by the gain of the first amplifier 58, whilst ensuring that the current flowing through the motor remains below a safe limit. The current limiting operation of the first PI controller 60 is explained in more detail below in relation to Figure 9. The battery 24, which was omitted from Figures 4 to 6 for the purpose of clarity, is shown in Figure 7 connected to the first h-bridge 48 and the second h-bridge 64 across which the second motor 32 is connected.

The piezoelectric crystal 42 generates a voltage proportional to the torque developed by the first motor 26. An attenuator 66 attenuates the voltage generated by the crystal 42 to generate a signal representative of a fraction of the torque developed by the first motor 26. The attenuated torque signal is applied to a second PI controller 68. A current sensor 70 generates a signal representative of the current flowing through the second motor 32 from the second h-bridge 64. A second microprocessor 72 generates a signal representative of an estimated torque developed by the second motor 32 and applies this signal to the second PI controller 68. The second PI controller generates a PWM voltage to drive the second h-bridge 64 so as to cause the second motor 32 to generate a torque equal to the fraction of the torque generated by the first motor 26.

Turning to Figure 9, the current limiting operation of the first PI controller 60 is shown. The PI controller 60 in fact comprises an outer, relatively slow PI controller 74, a current limiter 76 and an inner, relatively fast PI controller 78. In Figure 9 the first h-bridge 48, first motor 26, first rotary encoder 28, second clock 62 and current sensor of Figure 7 are represented by the functional block 80.

The outer PI controller 74 receives signals representative of a demanded motor speed from the amplifier 58 and signals representative of the actual motor speed from the first rotary encoder 28 and third clock 62 and generates a signal representative of a demanded current. The demanded current is that which will cause the actual motor speed to approach the demanded motor speed. The signal representative of the demanded current is transmitted to the current limiter 76, which either transmits the signal representative of the demanded current to the inner PI controller 78, or if the signal representative of the demanded current exceeds a threshold value, transmits a signal representative of a limited demanded current to the inner PI controller 78.

The inner PI controller 78 receives the signal representative of the demanded current (whether or not limited) and a signal representative of the actual motor current from the current sensor. The inner PI controller generates a PWM voltage to drive the first h-bridge so as to cause the actual current flowing through the motor to approach the demanded current.

Figure 10 shows a variation of the control scheme shown in Figure 7, in which a torque developed by the first motor is calculated from parameters of the first motor related to torque, rather than measured directly. The operation of the first motor 26, first rotary encoder 28, second motor 32, second rotary encoder 56, first clock 46, amplifier 58, first PI controller 60, first h-bridge 48, attenuator 66, second PI controller 68, current sensor 70, microprocessor 72 and third clock 62 is as previously described in relation to Figure 7. However, the first PI controller 60 receives the signals representative of the first motor current from voltage and current sensors 82 operable to generate signals representative of the voltage developed across, and current flowing in, the first motor 26.

The voltage and current sensors 82 transmit signals representative of the voltage developed across, and current flowing in, the first motor 26 to a second microprocessor 84. The second microprocessor also receives pulses from the first rotary encoder 28 and generates a signal representative of the load torque developed by the first motor 26, which is

transmitted to the attenuator 66. The second microprocessor 84 implements a model of the motor, which is explained in greater detail below with reference to Figure 14. The attenuated torque signal is transmitted to the second PI controller 68 to cause the second motor 32 to generate a torque proportional to the load torque generated by the first motor, which torque opposes the rotation of the handwheel 14, as previously described.

Turning to Figure 14, this shows the model implemented by the second microprocessor 84. In the following description it is to be assumed that signals representative of a particular variable are signals representative of the Laplace transform of that variable. The second microprocessor receives a signal representative of the voltage applied to the first motor 26, and the current through it and a signal representative of the angular displacement of the rotor of the first motor from a reference orientation. From previous angular displacement signals the second microprocessor determines the actual speed of rotation of the rotor of the first motor. Using the model an estimate of the motor current and speed may be made. The estimated speed of the motor enables a signal representative of the back emf generated by the first motor to be generated. The back emf signal is subtracted from the motor voltage signal to generate a signal representative of the estimated voltage across the windings of the first motor. The second microprocessor uses the estimated windings voltage signal to generate a signal representative of the motor current and of the total electrical torque generated by the first motor 26. The second microprocessor also generates a signal representative of a predicted load torque generated by the first motor by comparing the actual current and speed against the estimates and subtracts the signal representative of the predicted load torque from the signal representative of the total electrical torque to generate a signal representative of the accelerating torque developed by the first motor. The second microprocessor generates a signal representative of the estimated speed of rotation of the rotor of the first motor from the accelerating torque signal, from which the back emf signal referred to earlier is generated.

The second microprocessor generates from the estimated rotor speed signal a signal representative of the estimated angular displacement of the rotor from the reference orientation and compares the estimated angular displacement signal with a signal

representative of the actual angular displacement of the rotor generated by the first rotary encoder 28. The second microprocessor adjusts the predicted load torque signal to reduce the difference between the actual and estimated angular displacement signals and the difference between the actual and estimated motor current.

The variables shown in the model of Figure 14 are as follows:

$V_{drive}(s)$	~	Laplace transform of the voltage applied to the first motor 26;
K_I	~	torque constant of the first motor;
R	~	armature resistance of the first motor;
L	~	armature inductance of the first motor;
s	~	the Laplace variable;
$T_{elec}(s)$	~	Laplace transform of the total electrical torque of the first motor;
$T_{load}(s)$	~	Laplace transform of the load torque of the first motor;
$T_{accel}(s)$	~	Laplace transform of the accelerating torque of the first motor;
b	~	friction coefficient of the first motor and gearbox;
J	~	inertia of the rotor of the first motor and gearbox;
$\theta(s)$	~	Laplace transform of the estimated angular displacement of the rotor of the first motor;
K_ω	~	electric constant of the first motor; and
V_{bemf}	~	Laplace transform of the estimated back emf of the first motor.

Returning to Figures 11 and 12, the handwheel assembly of the drill of Figures 1 and 2 comprises the handwheel 14, folding handle 38, spindle 86 to which the handwheel is attached, circular thrust plate 88 through which the spindle 86 passes, and microswitch 90. The folding handle 38 is pivotally attached to the handwheel 14 and is formed with a cam 92. In the folded position (as shown in Figure 11) the cam does not engage with the thrust plate 88, which is biased towards the handwheel 14 by the microswitch. In the extended position, however, (as shown in Figure 12) the cam engages with the thrust plate 88, which causes the microswitch to be depressed, closing the microswitch. The second rotary encoder 56 is connected to the first clock 46 by the microswitch such that the handwheel is

operable to control the rotation of the chuck only when the handle 38 is in the extended position and the microswitch closed. When the handle 38 is in the folded position (and therefore inoperable to control the rotation of the chuck, the rotation of the chuck may be controlled by the trigger switch 20, in the manner known from conventional cordless drills.

Figure 13 shows a hand whisk 94 in accordance with the first aspect of the invention. It will be appreciated that the electric hand whisk has two chucks (not shown in Figure 13), one for each whisking element 96 and 98. The hand whisk 94 has a handwheel and a handle 102. In this embodiment of the invention the handle 102 is not foldable, since the whisk can be disabled simply by unplugging it from the mains electricity outlet to which it is connected.

Figure 15 shows the frequency response of a variable frequency digital low-pass filter with cut-off frequency plotted against magnitude of a signal representative of the speed of rotation of the handwheel. Cut-off frequency is plotted on the y-axis 106 and magnitude of the handwheel speed signal on the x-axis 108. The variable frequency digital low-pass filter could be used in any of the control schemes described above. In the control scheme shown in Figure 4, for example, the variable frequency low-pass filter would be interposed between the clock 46 and the h-bridge 48.

The filter, the frequency response of which is shown in Figure 15, is designed to be used in a control scheme that defines a maximum speed of rotation of the handwheel, such that increases of speed of rotation of the handwheel above the maximum speed do not cause a corresponding increase in the speed of rotation of the chuck. This is not an essential feature of the filter, however.

As can be seen from Figure 15, the filter passes all signals with frequencies below 50 Hz for speeds of rotation of the handwheel up to five percent of the maximum speed. For speeds of rotation of the handwheel between five and ten percent of the maximum speed the filter passes all signals with frequencies below 12 Hz. For speeds of rotation of the

handwheel between ten and one hundred percent of the maximum speed the filter passes all signals with frequencies below 3 Hz.

The effect of this is to slow the speed of response of the drill motor controller with increasing speed of the drill motor. This arrangement has been found to give very sensitive control of the speed of the chuck at low speeds of rotation of the chuck, for which a high speed of response of the drill motor controller is required, and relatively insensitive control of the speed of the chuck at high speeds of rotation of the chuck. It is important that the control of the speed of rotation of the chuck at high speeds of rotation of the chuck be relatively insensitive, since it is difficult for a user to maintain a constant, high speed of rotation of the handwheel, and the speed of rotation of the chuck would otherwise be variable to a degree that would irritate the user. This is because the user would be used to conventional mechanical drills, in which the inertia of the handwheel, gear train and chuck tend to prevent or reduce sudden variations in the user's speed of rotation of the handwheel.

Figure 16 shows an improved arrangement of a handwheel that forms part of a cordless drill. The handwheel 110 is mounted on a shaft that is attached to the body of the drill. A portion of the body is shown in Figure 16, denoted by reference numeral 114. A compression spring 115 is accommodated in a recess in the body and acts on a brake block 116. The brake block is covered by a felt pad 118 and arranged such that the action of the spring urges the felt pad 118 into engagement with a rear face of the handwheel 110.

In addition to preventing movement of the handwheel 110 due to the weight of a handle 120 attached to the handwheel, the brake block assists the smooth operation of the drill by the user, since the brake block resists abrupt changes of the speed of rotation of the handwheel by the user.

Figure 17 shows a drill 122 that is suitable for use by both left and right-handed users. The body of the drill is provided with symmetrically disposed sockets on opposite sides of the body. One such socket is shown in Figure 17, denoted by reference numeral 124. The

drill 122 is provided with a single, detachable handle 126 that can be placed into either of the sockets, depending on the handedness of the user. The handle contains a multipole magnet that, in conjunction with three Hall effect sensors (not shown) in the body of the drill, is used to detect rotation of the handwheel relative to the body of the drill. The body of the drill also contains a ferromagnetic keeper (not shown) adjacent to each socket that is acted on by the magnet in the handle to retain the handle in whichever socket it has been placed.

Turning to Figure 18, this shows a section through the drill 122 along a line of symmetry of the handwheel 126. The multipole magnet in the handwheel 126 is shown in Figure 18, denoted by reference numeral 128. Microswitches 130 and 132 are contained in each of the sockets and one of the microswitches is closed by insertion of the handwheel into the socket. In Figure 18 the microswitch 130 has been closed by insertion of the handwheel into the socket. The motor controller (not shown) of the drill determines into which socket the handwheel 126 has been inserted by determining which of the switches 130 and 132 has been closed. The motor controller controls the motor in response to rotation of the handwheel such that when the user holds the drill in one hand with the chuck pointing away from him, rotation of the handle of the handwheel towards the chuck (with the handle of the handwheel at top dead centre) causes clockwise rotation of the chuck (as seen by the user). This is regardless of whether the handwheel is on the left or right-hand side of the drill.

In Figure 18 a dust cover 134 is shown inserted into the spare socket. Insertion of the dust cover 134 into the socket does not close the microswitch 132.

It will be appreciated by those skilled in the art that, by having a set of three Hall effect sensors for each socket, the microswitches 130 and 132 can be dispensed with, because the motor controller can determine into which socket the handle has been inserted by the set of Hall effect sensors from which it receives signals produced by rotation of the handle, and control the direction of rotation of the chuck accordingly.

Figure 19 shows another drill 136 suitable for use by both left and right-handed users. The body of the drill includes a rotatable collar 138 to which a handwheel 140 is attached. The collar is rotatable through 180 degrees relative to the rest of the body, so that the handwheel is disposed either on the left or right-hand side of the body.

Turning to Figure 21, this shows a section through the drill 136 along a line of symmetry of the handwheel 140. The internal surface of the collar 138 is provided with first and second inwardly projecting lugs 142 and 144. The lugs are engageable with respective first and second microswitches 146 and 148 that are disposed inside the body of the drill. In Figure 21 the second lug 144 is shown engaged with the second microswitch 148. Engagement of a lug with its respective microswitch closes the microswitch.

The motor controller (not shown) is operable to determine to which side of the drill the user has rotated the collar by whichever of the microswitches 146 and 148 is closed and to control the motor so that, whichever side of the body the handwheel is disposed, rotation of the handle of the handwheel away from top dead centre towards the chuck causes the chuck to rotate clockwise as seen from behind by the user.

Turning to Figure 20, this shows another drill 150 suitable for both left and right-handed users. The drill 150 is provided with two handwheels 152 and 154 disposed symmetrically on the left and right-hand sides of the drill. The handwheels are fitted with respective handles 156 and 158 that are movable between extended and closed positions. The handle 156 of the handwheel 152 is shown in Figure 20 in the extended position and the handwheel 158 of the handwheel 154 is shown in the closed position.

As described in relation to Figures 11 and 12, the handles 156 and 158 are formed with respective cam surfaces 160 and 162. The drill 150 further comprises a toggle switch 164 and a yoke 166 that is engageable with the toggle switch 164 and the cam surfaces 160 and 162 of the handles. In Figure 20, the cam surface 160 of the handle has engaged with the yoke 166 as a result of the handle being moved to the extended position. This has caused the yoke to close the toggle switch 164. If the handle 156 were to be moved to the closed

position and the handle 158 moved to the extended position, the cam surface 162 of the handle 158 would engage with the yoke 166 and cause the yoke to open the toggle switch 164.

A motor controller (not shown) of the drill 150 is operable to determine from whether the toggle switch 164 is open or closed, whether the user of the drill is using the handwheel 152 or 154, and, as explained above, to ensure that forward rotation of the handwheel used by the user causes clockwise rotation of the chuck of the drill.

Figure 23 shows the drill 150 of Figure 20 with both of the handles 156 and 158 of the handwheels 152 and 154 in their extended positions. In practice, this situation would not arise, because the yoke 166 shown in Figure 20 would prevent the other handle from being moved to the extended position when one handle was already in the extended position.

Turning finally to Figure 22, this also shows a drill 168 suitable for both left and right-handed users. The body of the drill comprises a housing 170 to which a handwheel 172 is attached and a handgrip 174 that is pivotally attached to the housing 170. The handgrip 174 is rotatable relative to the housing 170 between a first, left-handed position (shown by a dotted line and denoted by reference numeral 176) and a second, right-handed position (shown also by a dotted line and denoted by reference numeral 178). The handgrip 174 is formed with a lug 180 and is engageable with a first microswitch 182 in the first position and with a second microswitch 184 in the second position. When engaged with a microswitch, the lug closes the microswitch.

A motor controller (not shown) of the drill 168 is operable to determine which of the microswitches 182 and 184 is closed and hence whether the handgrip is in the first or the second position. A right-handed user of the drill would hold the handgrip in his left hand and operate the handwheel 172 with his right hand with the handgrip in the first position. A left-handed user would hold the handgrip in his right hand and operate the handwheel 172 with his left hand with the handgrip in the second position. The motor controller is operable by determining which of the microswitches 182 or 184 is closed to control the

motor of the drill (not shown) in response to rotation of the handwheel 172 such that with the chuck 186 pointing away from the user, rotation of the handwheel towards the chuck with the handle of the handwheel (not shown) at top dead centre causes clockwise rotation of the chuck as seen from the rear end of the chuck by the user.

It will be apparent that although the foregoing description relates to several embodiments of the invention, the invention encompasses other embodiments as defined by the foregoing statements of the invention.